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A. Task Objective: Algorithm Development for Global Mapping of
Phycoerythrin Pigment, Dissolved Organic Matter, and Chlorophyllous
Pigment

As reported during the last semi-annual period, a significant advance in the retrieval of inherent optical properties (whose list includes phycoerobilin absorption coefficients and phycoerythrobilin absorption coefficients) was published. The algorithm method is a major departure from the radiance ratios used in the old CZCS algorithms. The new method is based on radiance models derived from the radiative transfer equation (RTE). The linear matrix inversion technique is detailed in : Hoge, Frank E. and Paul E. Lyon, "Satellite Retrieval of Inherent Optical Properties by Linear Matrix Inversion of Oceanic Radiance Models: An Analysis of Model and Radiance Measurement Errors", Jour. Geophys. Res. 101, 16,631- 16,648, (1996). Work is now underway to extend the method to include phycoerobilin and phycoerythrobilin absorption coefficients within the matrix inversion. No problems are anticipated with this mathematical extension effort. The major obstacle is the development of IOP models for total constituent backscatter, and absorption models for phycoerobilin and phycoerythrobilin. These are of course under intense development within our project. The principal advantage of the matrix inversion method is that it can be extended to include any number of absorbers and backscatterers. Thus it possesses unlimited potential for general algorithm development.

1. MODIS North Atlantic Test Site Establishment and
Characterization

The Test Site includes the New York Bight/Mid-Atlantic Bight/Gulf Stream/Sargasso Sea and is conveniently located north and east of GSFC/WFF. As previously reported, the MODIS North Atlantic Test Site has been established as originally proposed. Much of the data obtained in the northwestern portion of the test site will be used for algorithm development in Case 2 waters. Characterization has been initiated by ship sampling, aircraft overflights, and analysis of historical data available from within the NASA AOL project since 1980.

a. During this third quarter reporting period airborne missions were flown in the MODIS Test Site during late August and early September 1996 in conjunction with the the Russian Shirshov Institute of Oceanology. The flights were conducted near the ship cruise led by U. MD scientist Dr. Neil Blough. The cruise lines to the Gulf Stream were overflown on the northern portion and the southern portion. Backscatter instrumentation, a BBC-4, was supplied by Dr. Robert Maffione of SRI (now of Sequoia Instruments in Seattle, Washington). These airborne missions (and preliminary

test flights) will allow further development of the phycoerythrin pigment algorithm. They will also provide additional evaluation of the recently-rebuilt AOL system and will provide data needed to further calibrate the fluorescence/Raman ratios derived from the AOL spectrometer data to retrieve CDOM and chlorophyll absorption coefficients.

As previously suggested, the above airborne flights allow continued evaluation of a new 256 channel ocean color spectrometer designed and built at Wallops Flight Facility. It was found that the color sensor possessed the requisite sensitivity for ocean color spectra in a high-rate/low-integration-time mode needed to allow editing of data containing sun glint. The prototype sensor was successfully flown during the JGOFS Iron Enrichment Experiments off the coast of Ecuador in November 1993. A still higher sensitivity detector and higher resolution sensor was successfully flown in March 1995 and during the JGOFS Arabian Sea Experiment. Preliminary evaluation of the data suggests that it is of good quality.

A manuscript describing some of the chromophoric dissolved organic matter (DOM) retrieval needed for the phycoerythrin algorithm work was published during a previous reporting period. The reader should consult this paper for details of the progress of the DOM retrieval using fluorescence methods. The paper is: Hoge, F.E., M.E. Williams, R.N. Swift, J.K. Yungel, and A. Vodacek, Satellite retrieval of the absorption coefficient of chromophoric dissolved organic matter in continental margins, *Jour. Geophys. Res.* 100, 24847-24854, (1995b).

This paper is complemented by a previous one that details the retrieval of CDOM absorption coefficient with airborne lasers: *Inherent Optical Properties of the Ocean: Retrieval of the Absorption Coefficient of Chromophoric Dissolved Organic Matter from Airborne Laser Spectral Fluorescence Measurements* by Frank E. Hoge, Anthony Vodacek, Robert N. Swift and James K. Yungel, *Applied Optics* 34, 7032-7038 (1995). The CDOM and the chlorophyll absorption must be satisfactorily modeled and retrieved before the weakly-absorbing phycoerythrin can be retrieved.

b. As previously reported, modifications to the AOL now have allow the discrimination of phycoerythrobilin and phycourobilin during airborne flights and the data are now being analysed for publication. Specifically, phycoerythrin fluorescence has been observed from airborne platforms since 1979. However, the spectral shifts associated with the individual phycobiliproteins (PBP), phycourobilin (PUB) and phycoerythrobilin (PEB), were not readily observable. Modifications to the original NASA Airborne Oceanographic Lidar (AOL) optics now permit spectral shifts associated with PEB and PUB pigments to be observed. This in turn allows possible application of the airborne methodology to wide area mapping of PEB and PUB spatial variability. This will significantly enhance the modelling and retrieval of these pigment absorptions due to phycoerythrin. A manuscript is now in

preparation to report the observation of airborne laser induced spectral shifts associated with PUB and PEB pigments.

During 1995, three manuscripts were published relative to forward modeling and inverse modeling (directly related to the retrieval of phycoerythrin from water-leaving radiances).

1. Hoge, F.E., M.E. Williams, R.N. Swift, J.K. Yungel, and A. Vodacek, Satellite retrieval of the absorption coefficient of chromophoric dissolved organic matter in continental margins, *Jour. Geophys. Res.* 100, 24847-24854, (1995b).
2. Hoge, Frank E., Robert N. Swift, and James K. Yungel, Oceanic radiance model development and validation: Application of airborne active-passive ocean color spectral measurements, *Applied Optics*, 34, 3468-3476, (1995).
3. Hoge, Frank E., Anthony Vodacek, Robert N. Swift, James Y. Yungel, Neil V. Blough, Inherent optical properties of the ocean: Retrieval of the absorption coefficient of chromophoric dissolved organic matter from airborne laser spectral fluorescence measurements, *Applied Optics* 34, 7032-7038, 1995

Manuscripts describing some of the algorithm work were published during the previous reporting period. The reader should consult these papers for details of the progress of the DOM retrieval using fluorescence methods. The manuscripts are:

(a) Hoge, Frank E., Anthony Vodacek, Neil V. Blough, "Inherent Optical Properties of the Ocean: Retrieval of the Absorption Coefficient of Chromophoric Dissolved Organic Matter from Fluorescence Measurements", *Limnology and Oceanography*, 38(7) 1394-1402, 1993.

(b) Vodacek, Anthony, Frank E. Hoge, Robert N. Swift, James K. Yungel, Edward T. Peltzer, Neil V. Blough, The detection of in situ and airborne fluorescence measurements to determine UV absorption coefficients and DOC concentration in surface waters, *Limnology and Oceanography*, 40, 411-415 (1995).

The validity of the Test Site samples and data were addressed during the prior reporting period. Specifically, the DOM absorption from prior cooperative ship experiments (see above paper) have been used to establish the levels of DOM fluorescence measured with the NASA Airborne Oceanographic Lidar in both the Atlantic and Pacific Oceans. These results were published during a previous reporting period. The reference is : Hoge, Frank E., Robert N. Swift, James Y. Yungel, Anthony Vodacek, "Fluorescence of Dissolved Organic Matter: A Comparison of North Pacific and North Atlantic Oceans during April 1991", *Jour. Geophysical Res.* 98, No. C12, 22,779-22,787 (1993).

B. Other Work Accomplished

1. Satellite Data Analysis

The retrieval of phycoerobilin and phycoerythrobilin has been advanced by the recent demonstration of the retrieval of chromophoric dissolved organic matter from CZCS data. The results have been published in JGR as discussed above: Hoge, F.E., M.E. Williams, R.N. Swift, J.K. Yungel, and A. Vodacek, Satellite retrieval of the absorption coefficient of chromophoric dissolved organic matter in continental margins, Jour. Geophys. Res., in press, 1995. This is an important step toward the ultimate goal of retrieving CDOM, chlorophyll absorption coefficient, phycoerythrin absorption coefficient and total constituent backscatter.

2. In Situ Optical Characterization of the MODIS North Atlantic Test Site.

The continued characterization of the Test Site is partially described in the previously mentioned publications.

A. As indicated, cooperative overflights within the MODIS Test Site were conducted in conjunction with ONR/Univ. MD during the reporting period.

1. Phycoerythrin Algorithm Development Activities

Plans call for us to again directly address the quantification of the phycoerythrin signal as outlined in the original MODIS proposal. The phycoerythrin retrieval is being dealt with by inversion of ocean radiance models. Details of the phycoerythrin retrieval appear in the ATBD as submitted to the project office.

2. Chlorophyll Pigment and CDOM Corrections to the Phycoerythrin Algorithm.

As previously reported, major perturbations or influence to the ocean color spectrum are provided by chlorophyll, CDOM, and total constituent backscatter. These oceanic constituents significantly impede the retrieval of phycoerythrin pigment from the upwelled radiances. They must be dealt with in a systematic way in order to understand their effects and the impact on the retrieval of phycoerythrin and its ultimate quantification. In situ and airborne data gathered to date will be used to model the effects and to ascertain the extent that they can be quantified and removed. Recently published chlorophyll pigment models are being used for the pigment absorption. Our own CDOM model is being used for recovery of chromophoric dissolved organic matter. Finally, the literature is being surveyed for the best available detritus absorption model. The most pressing modeling problem is the availability of suitable chlorophyllous and nonchlorophyllous particulate backscatter models.

C. Anticipated Activities During Next Quarter

1. Additional flights of the NASA Airborne Oceanographic Lidar are planned within the MODIS Test Site. Specifically, flights to obtain better passive data for phycoerythrin retrieval.

2. No international field excursion are planned during

1996.

D. Other Concerns

As reported previously, the lack of a 600nm band on MODIS-N is no longer felt to be the biggest problem facing the retrieval of the phycoerythrin pigment. Additional effort since the last report still suggest that radiance (and reflectance) models, can provide retrieval of the phycoerythrin pigment at the absorption peaks of 495nm (phycourobilin, PUB) and 545nm (phycoerythrobilin, PEB) can be achieved using the 490nm and 555nm MODIS bands. Of course, such retrievals will require a highly accurate model to account for the significant amounts of chlorophyll and DOM absorption occurring simultaneously with the phycoerythrin absorptions. The details of the phycoerythrin retrieval have been recently detailed in the ATBD but are being upgraded to linear matrix inversion of a radiance model that includes the phycoerythrobilin and phycourobilin absorption coefficients.